In-Space Propulsion (ISP) Aerocapture Technology

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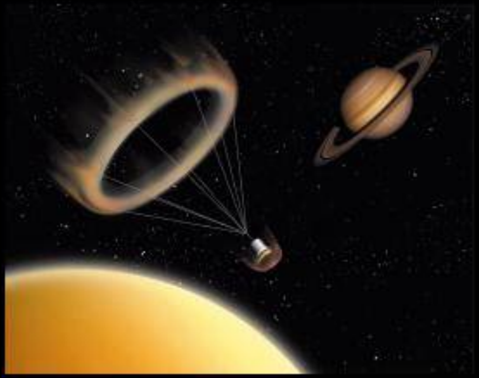
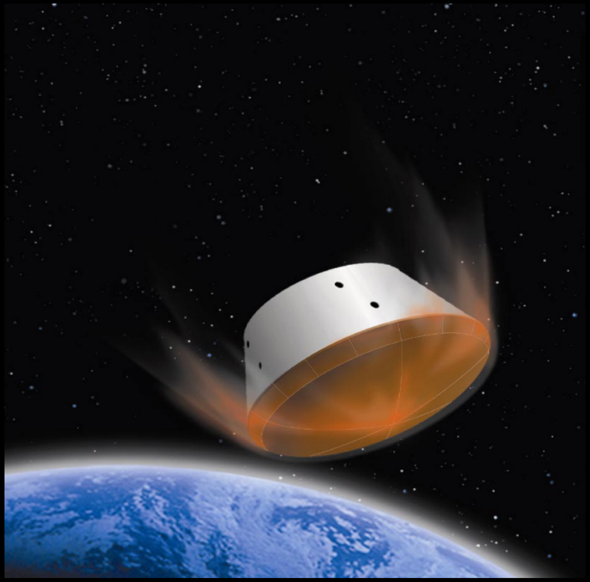




2nd International Planetary Probe Workshop

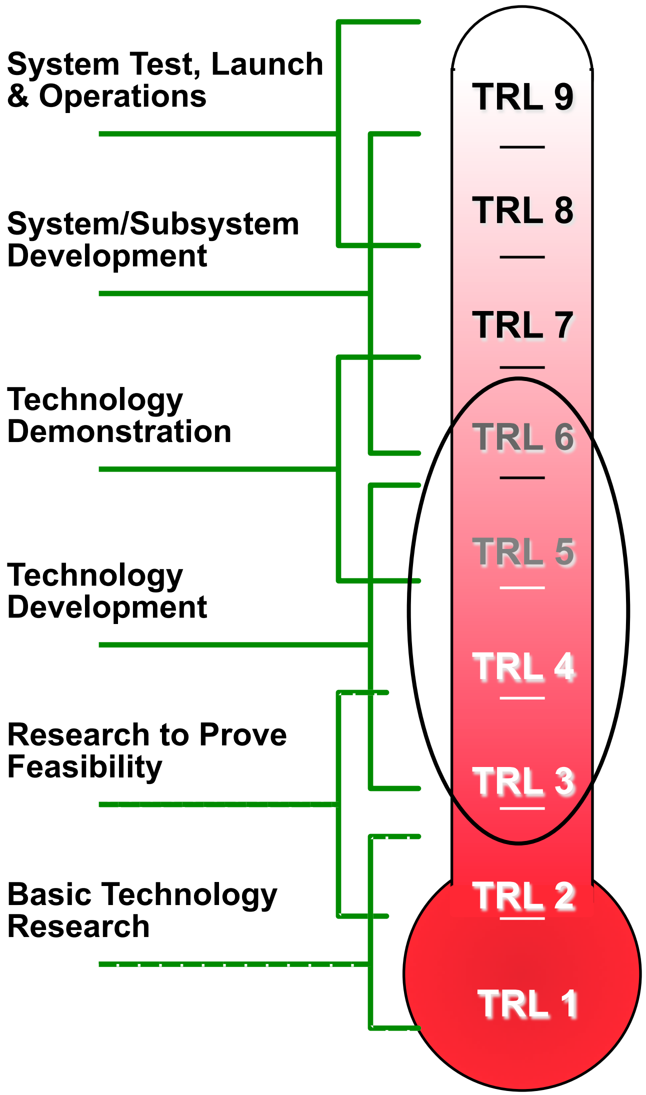
Moffett Field, CA

August 25, 2004

Purpose

- To raise awareness of NASA's investments in Aerocapture technology through the In-Space Propulsion Program
- To highlight the synergies between these investments and entry probe technology needs

In-Space Propulsion Program



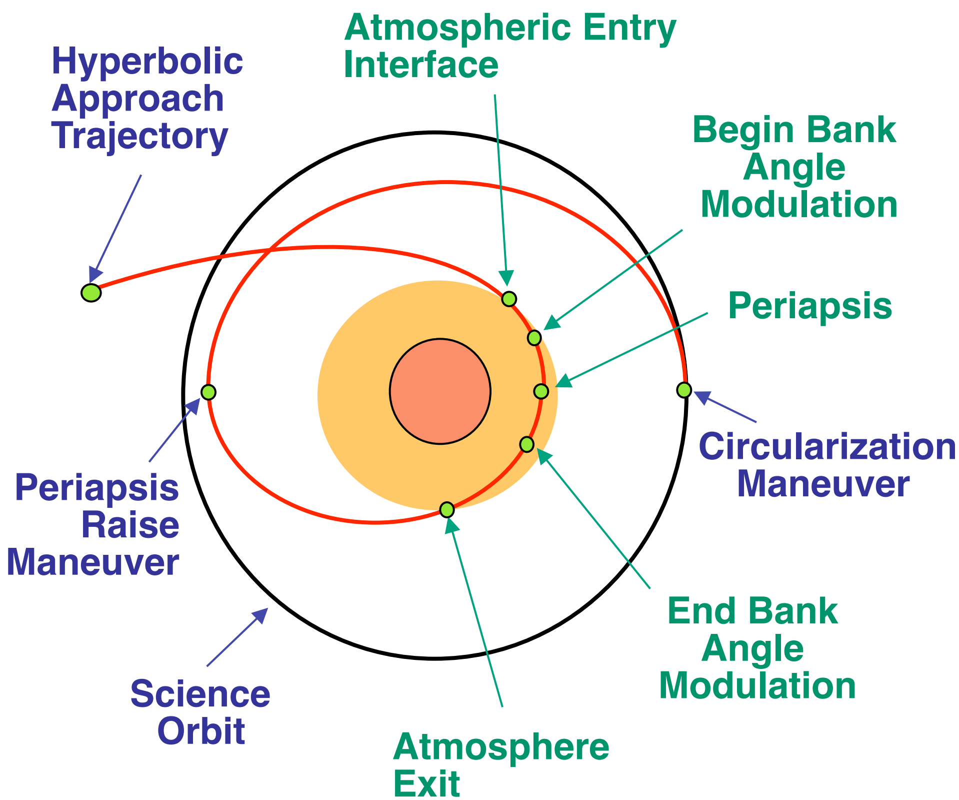
- Funded by the NASA's Science Mission Directorate (Code S)
- Charter is to develop primary propulsion technologies from TRL3 to TRL6 within 3-5 years, to reduce mass, cost, and trip time for solar system exploration missions
- In 2002, a prioritization process showed aerocapture to be beneficial, or enabling, for many destinations with atmospheres

High Priority	Medium Priority	"Emerging" Low Priority
Aerocapture	Advanced Chemical	Solar Thermal Propulsion
Next Generation Ion Propulsion (5/10 kW)	Solar Electric Propulsion (Includes Hall)	Momentum Exchange Tethers
Solar Sails		Solar Sails (1 g/m^2)

Aerocapture Overview

Features

- Much higher useful payload fraction than for standard chemical propulsion or aerobraking orbit establishment
- Achieves required orbit faster than with aerobraking (hours vs. weeks/ months)
- Spacecraft protection necessary
- Requires autonomous GN&C
- Key disciplines:
  - Aerothermodynamics
  - Atmospheric modeling
  - Guidance, navigation and control
  - Trajectory design
  - Structures and materials
  - Thermal protection systems
  - Instrumentation
  - Systems engineering and integration

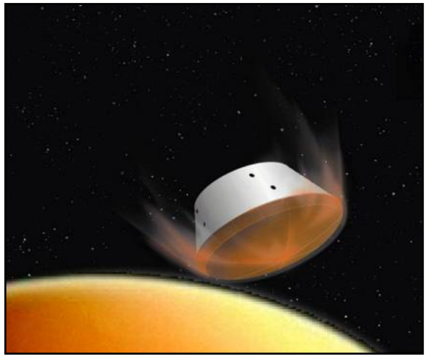


Aerocapture Technology Alternatives

Higher TRL

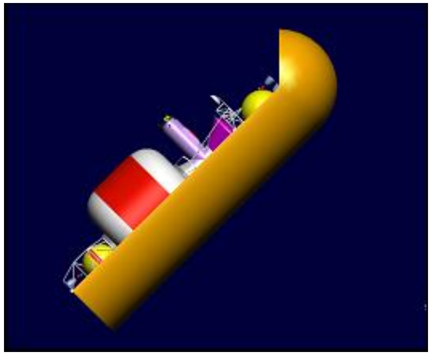
Lower TRL

Blunt Body Designs



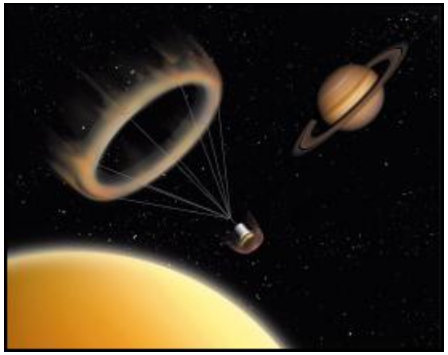
- Moderate to high maturity for small bodies; low to moderate maturity for other planets
- Provides modest tolerance for nav and atmospheric uncertainties

Slender Body Designs



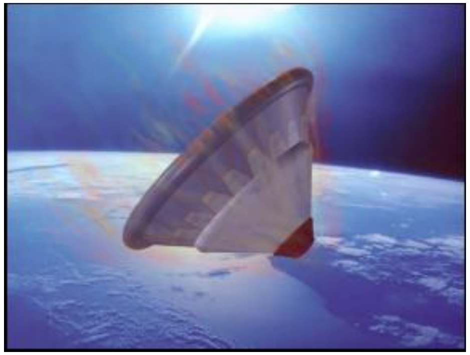
- Low to moderate maturity
- Provides increased tolerance for nav and atmos. uncertainties
- Design originally for human missions to Mars. Studies indicate that slender body designs are required for outer planet missions.
- Provides increased volume and improved packaging advantages for larger spacecraft.

Trailing Ballutes



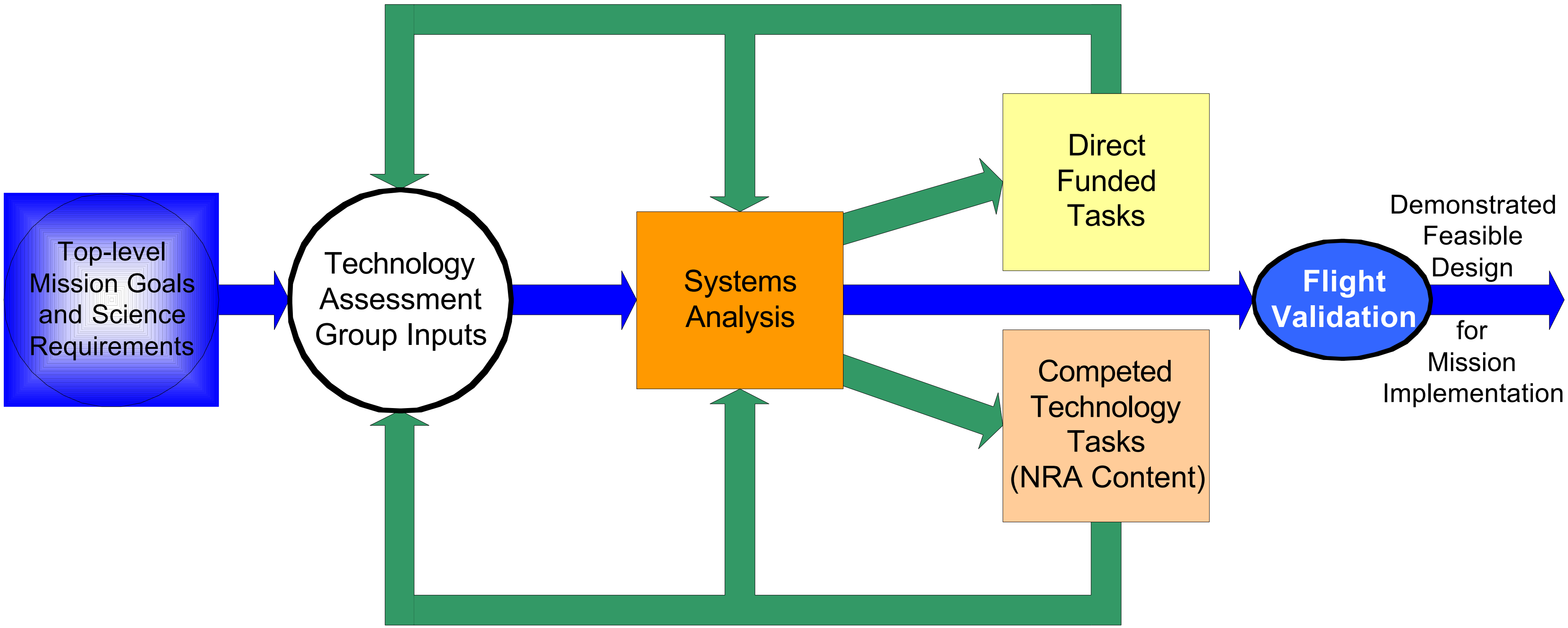
- Low maturity
- Applicable to all size and shape payloads
- May have performance advantages over Blunt Body, such as not having the payload enclosed during interplanetary cruise
- Potentially lower-mass than a rigid aeroshell

Attached Ballutes



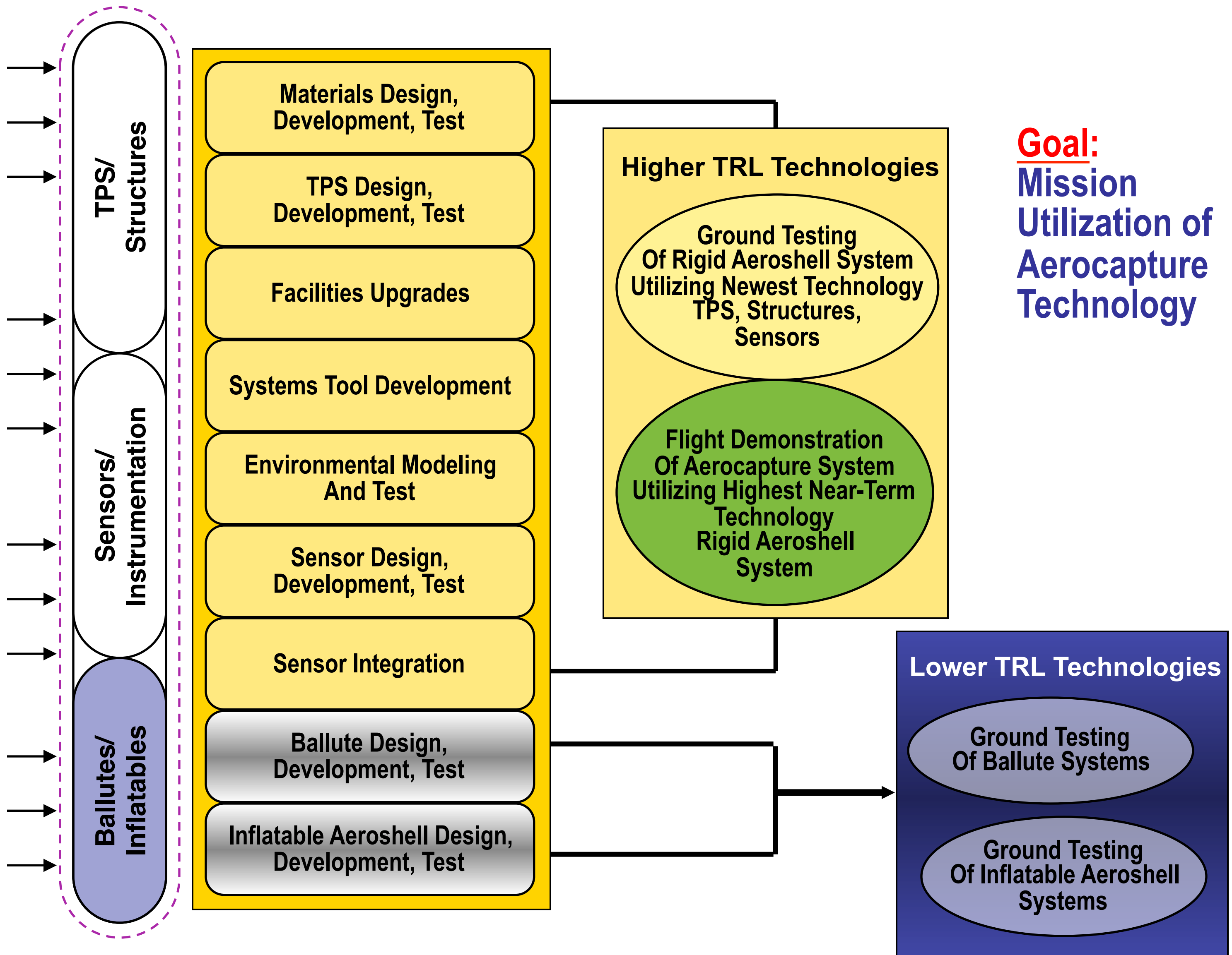
- Low to moderate maturity for Earth and Mars
- Developed and launched in 1996 by Soviet Union as part of Mars penetrator mission. Launch vehicle failure.
- Investigating feasibility of using aerodynamic lift for precision trajectory control
- Has potential volume and packaging advantage for larger spacecraft

Aerocapture Technology Project Process



Results from 2002 Aerocapture TAG

- **Adaptability of current materials**
- **Optimizing TPS design**
- **Test facility readiness**
- **Test facility limitations**
- **Diagnostic sensor performance in harsh environments**
- **Integrating sensor/ instrumentation with aerocapture systems**
- **Simulating flight environments in computer modeling and ground tests**
- **Environmental uncertainty**
- **Advancing lower TRL, higher risk technologies quickly**
- **Overall system integration**

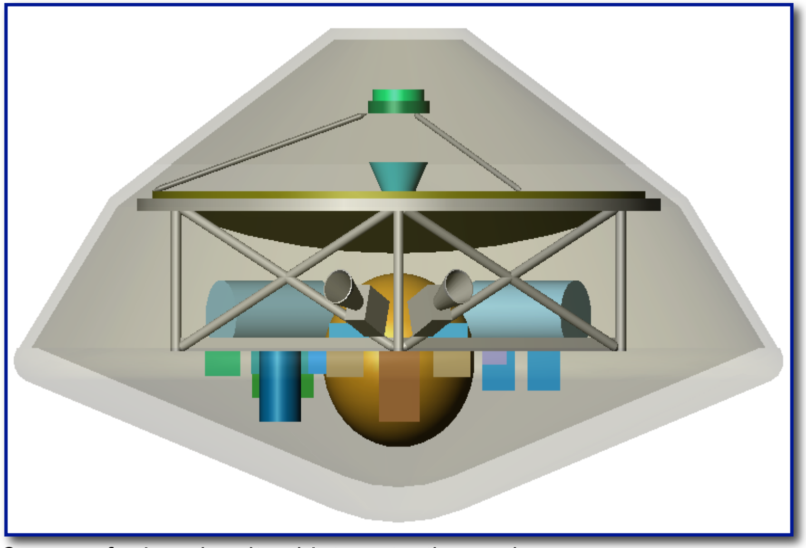


Technology Challenges → System Elements → Technology Development → Near-term Product → Mid-term Product

“Bounding Case” Requirements
(Stagnation Point Values)

Titan Aerocapture

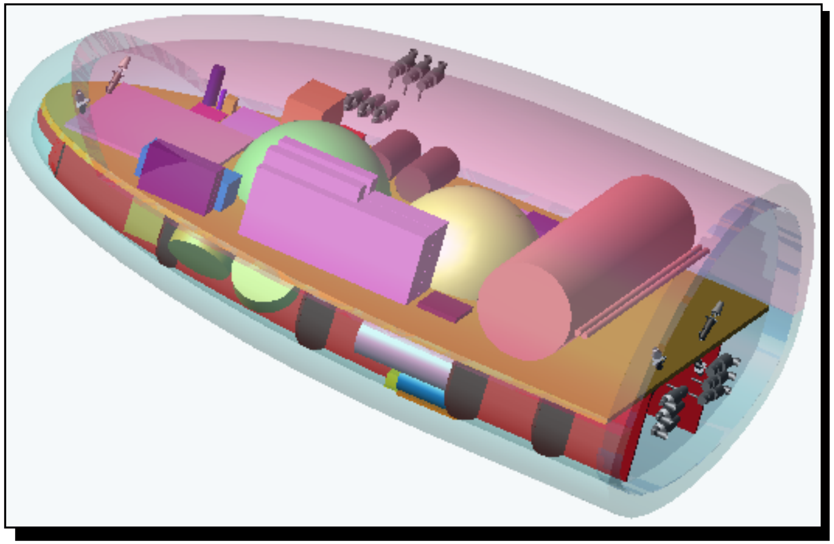
- Convective Heating: 50 W/cm^2
- Radiative Heating: 90-280 W/cm^2 (CN radiation, 3800-4200Å)*
- Time in Atmosphere: 42 minutes
- Ballistic Coefficient: 90 kg/m^2
- Aeroshell Mass Fraction: 39%



*Concern for low-density ablators; testing underway

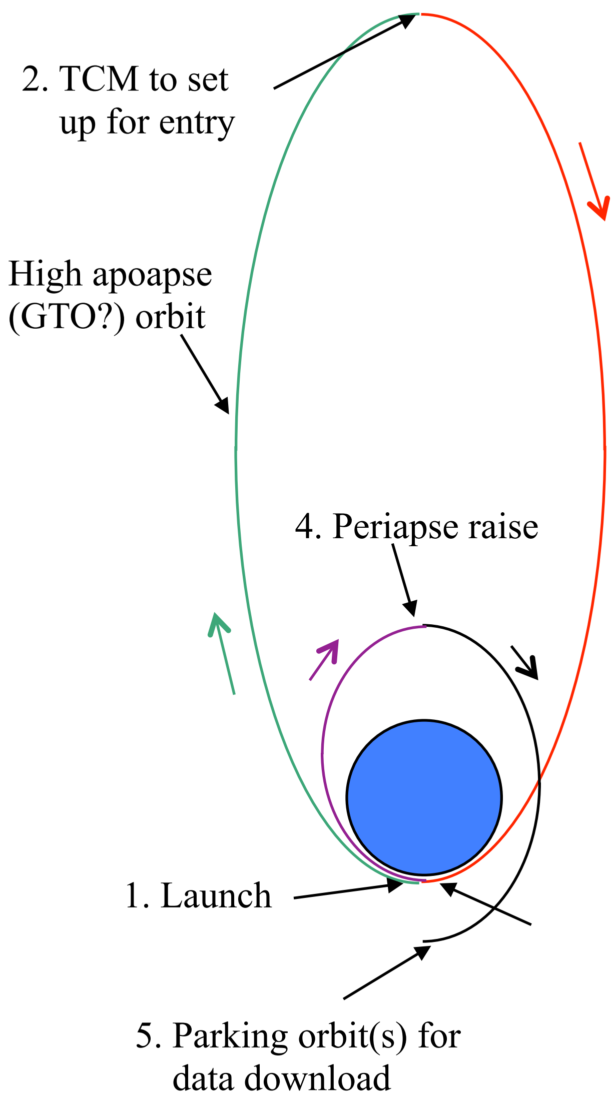
Neptune Aerocapture

- Convective Heating: 8000 W/cm^2
- Radiative Heating: 4000 W/cm^2
- Time in Atmosphere: 10 minutes
- Ballistic Coefficient: 895 kg/m^2
- Aeroshell Mass Fraction: 48%



ST9 Flight Demonstration Opportunity

- The past decades of NASA experience indicate that aerocapture will not be adopted for a planetary science mission without a precursor flight test
- Aerocapture is one of 5 concepts in competition for the New Millennium Program's ST9 flight demonstration opportunity
- Technology NRA is currently out for draft; once providers chosen, Phase A proposals due Sept '05 and selection/ATP Nov '05.
- Flight in 2008 would enable <u>mission infusion by 2012</u>
- Necessitated by NMP cost constraints, an Earth orbit aerocapture flight experiment is sufficient from a technical perspective

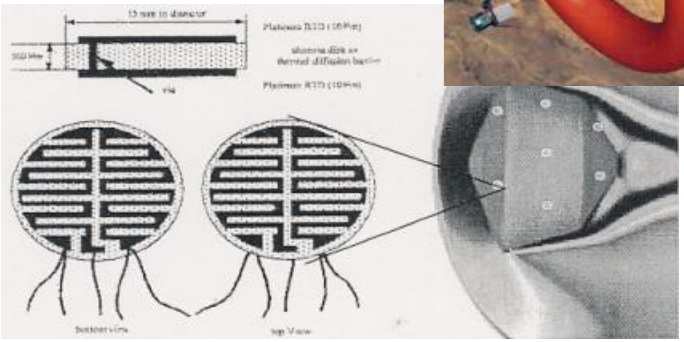


Note: Chart from Jeff Hall/JPL.

Aerocapture NRA Content: Cycles 1 and 2

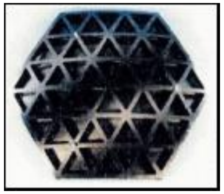
Cycle 1: <u>Design, Fabrication and Test of:</u>

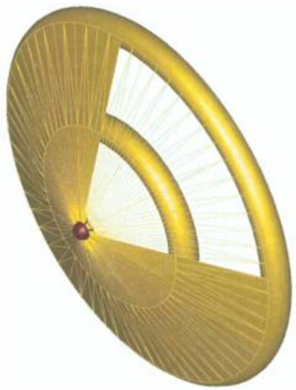
- Thermal Protection Systems/Structures
- Sensors/Instrumentation for Rigid Aeroshells
- Trailing Ballute System

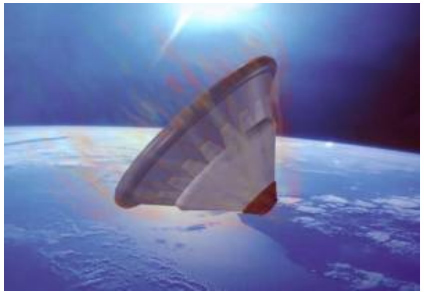


Cycle 2: <u>Analysis, Design and Test of:</u>

- Attached Ballutes/ Aftbody
- Attached Ballutes/ Forebody (Inflatable Aeroshells)

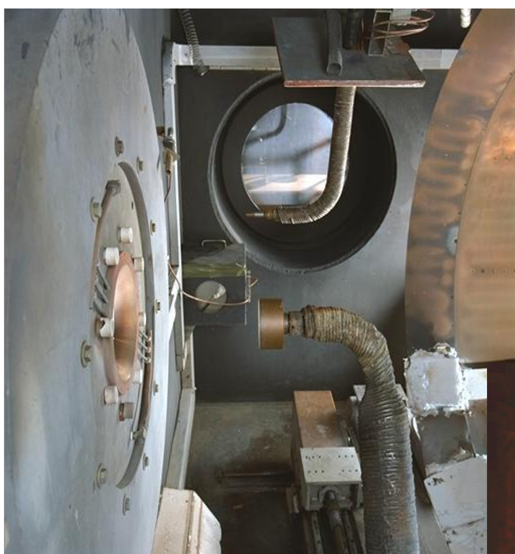


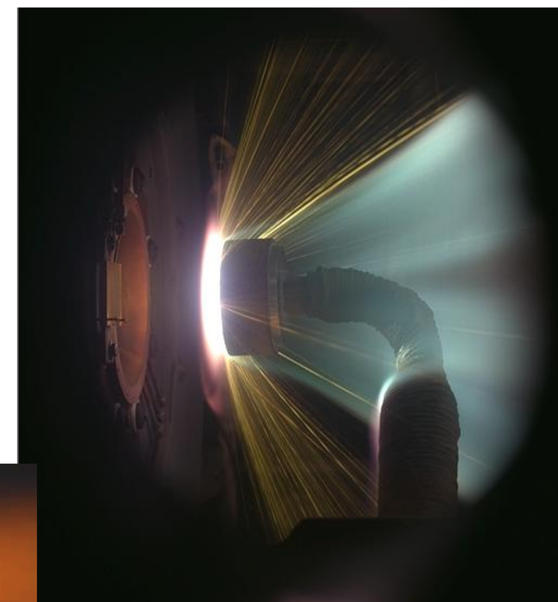


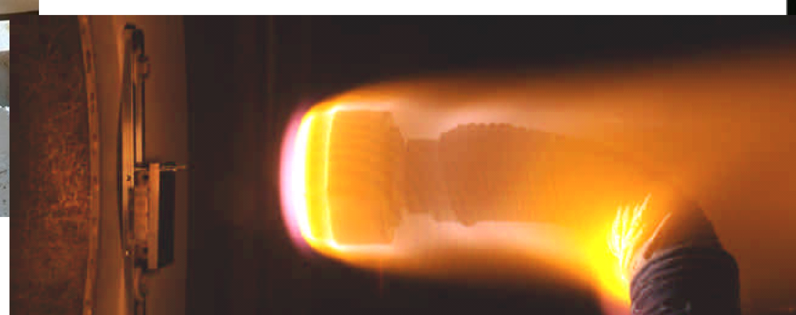


Ames Research Center TPS Development

- **Summary** - The Ames Research Center task combines aerothermal analysis with material screening and characterization to result in improved computational methods and new TPS choices for multiple destinations.
- **Accomplishments**
  - Completed shock tube testing for Titan kinetics (EAST facility)
  - Preliminary CFD analysis for radiation coupling, base flows, and afterbody flows completed
  - Me/Xe lamp facility set up for Titan radiation testing
- **Plans**
  - Complete radiation screening tests on multiple TPS materials
  - Radiation model validation/calibration based on EAST results
  - Arcjet testing of candidate TPS materials for Titan







Arcjet testing of TPS ablator samples at Ames

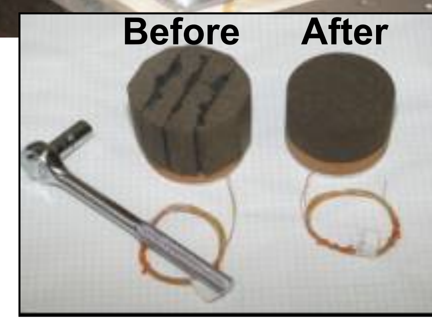
Applied Research Associates TPS Development

- **Summary** - ARA is developing and testing candidate ablator materials for aerocapture TPS systems. Test samples are formulated at the ARA facility in Denver and tested at various facilities that simulate the aerocapture environment.
- **Accomplishments**
  - –Completed extensive arcjet testing at ARC facilities
  - –Laboratory characterization and testing
- **Plans**
  - –Complete high-heat-rate testing (up to ~1000 W/cm^2)
  - –Update high-fidelity response models
  - –Demonstrate TPS/structures integration, and test

Slices of ablator material ready for assembly into sub-scale ellipsled heatshield

Ablator samples after arcjet testing

Solar Tower Testing

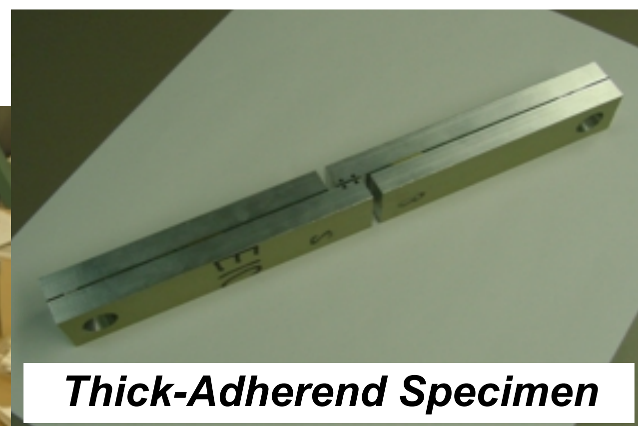


Ablator samples are CNC milled to precise tolerances

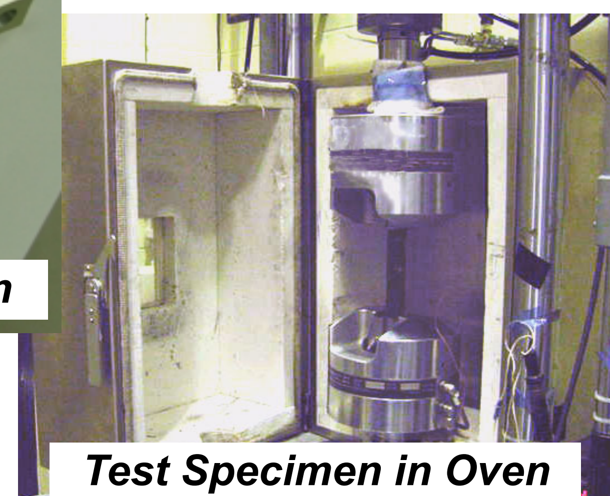
LaRC Structures Development

- **Summary** - LaRC seeks to reduce the mass of the aeroshell system by raising the temperature of the bondline between the structure and the TPS. The team (LaRC, ARA, Wichita State) has selected 3 new resins for the composite structural facesheets, and 15 candidate high-temperature adhesives. ARA TPS materials will be bonded to the advanced structures, in increasing sizes, and the systems will be tested in relevant environments.
- **Accomplishments**
  - Adhesives and resins researched and procured
  - ASTM laboratory test plans in place and lap shear test specimens manufactured
- **Plans**
  - Complete composite materials manufacture and testing (using new resins)
  - Downselect adhesives for component fabrication
  - Integrate aeroshell systems and test

Specimen Preparation



Thick-Adherend Specimen

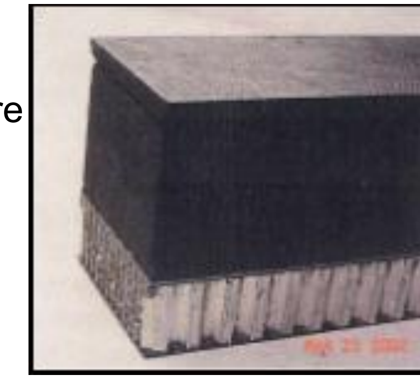


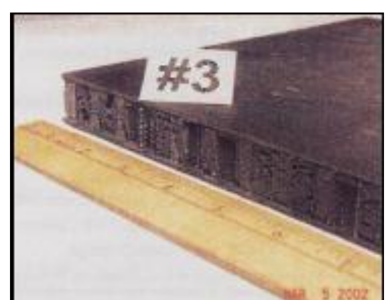
Test Specimen in Oven

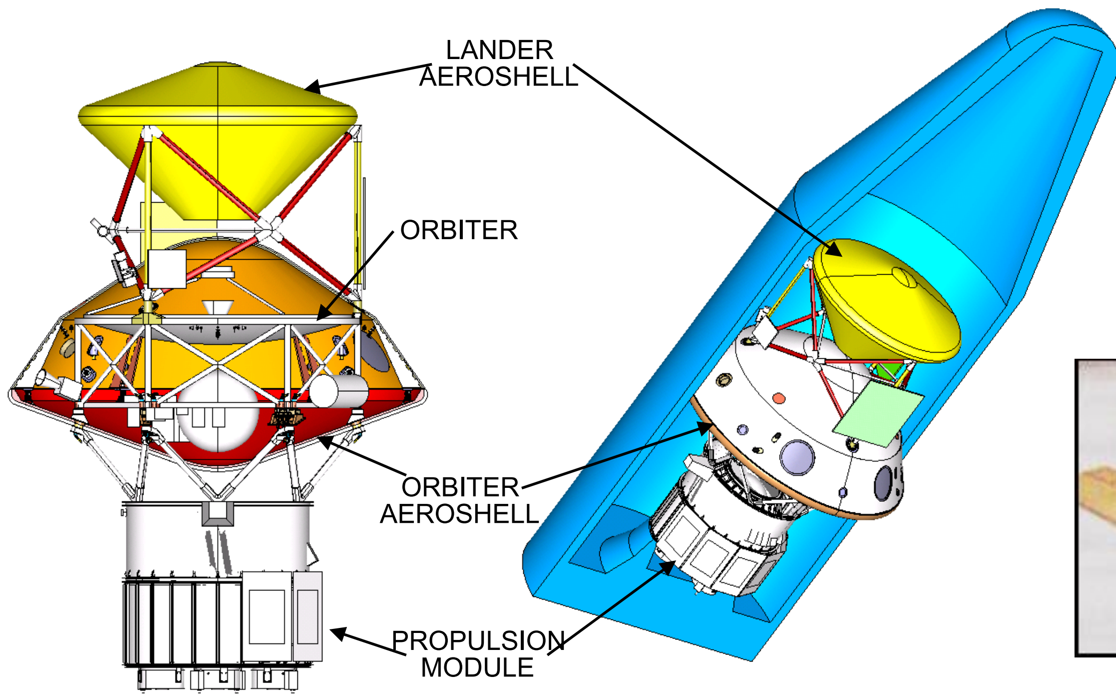
Lockheed Martin Astronautics Aeroshell Development

- **Summary** - Lockheed Martin Astronautics will develop 3 aeroshell concepts to meet the requirements of their conceptual design of a Titan mission aeroshell. Thermal and mechanical tests of each concept will be conducted and the mid-level concept will be built and tested on a 2-meter diameter scale.

- **Accomplishments**
  - Arcjet testing and elevated-temperature mechanical testing for warm structure
  - Preliminary design of Titan aeroshell complete
- **Plans**
  - Manufacture Carbon-Carbon rib-stiffened and honeycomb structure samples
  - Perform materials, coating, and insulation laboratory tests
  - Perform arcjet and mechanical testing on Carbon-Carbon structures



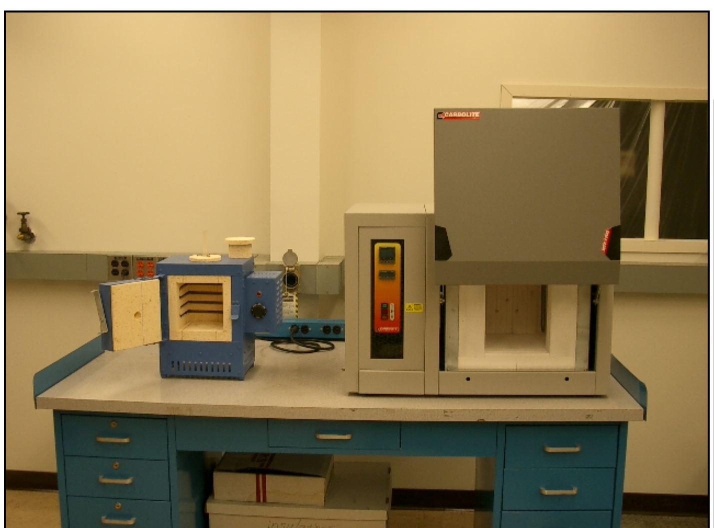


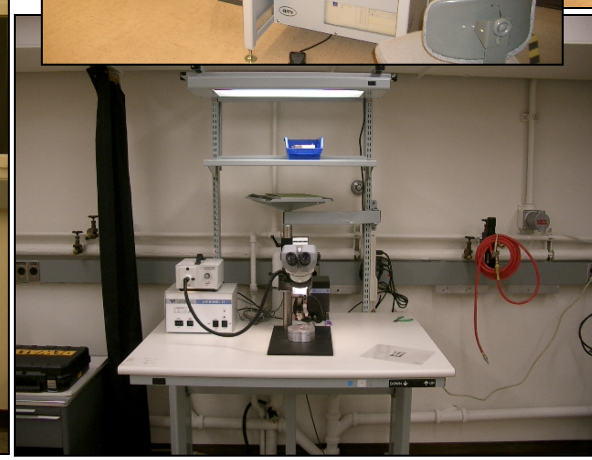


Samples of LMA hot structure materials

ELORET/ARC Sensor Development

- **Summary** - ELORET/ARC are developing heat flux and recession sensors for rigid aeroshells
- **Accomplishments**
  - Sensor manufacturing equipment identified, procured, and lab setup complete
  - Sensor design complete
  - Task plans completed and collaboration underway with APL for data acquisition system (Mars program partnership)
  - Initial arcjet performance tests completed--heat flux sensors operated for multiple cycles, at heat rates up to 15 W/cm^2
- **Plans**
  - Begin manufacturing sensors
  - Set up laboratory arcjet capability
  - Integrate sensors with new TPS materials

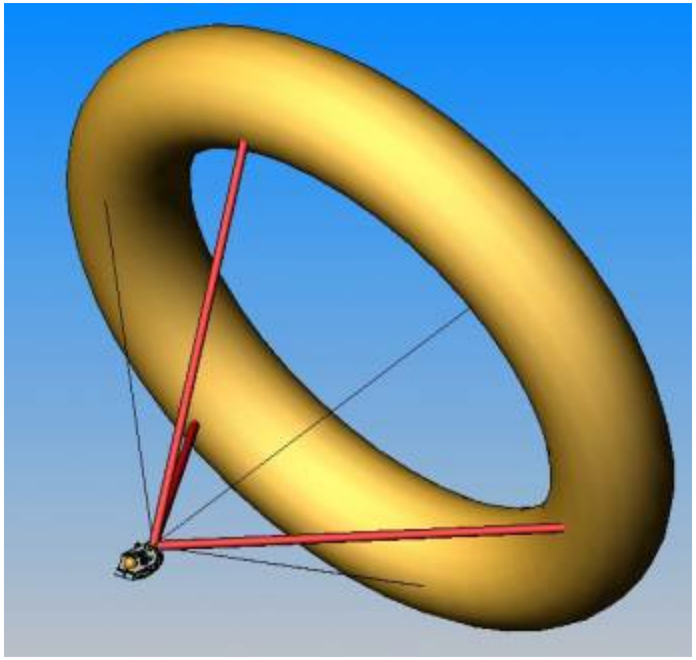




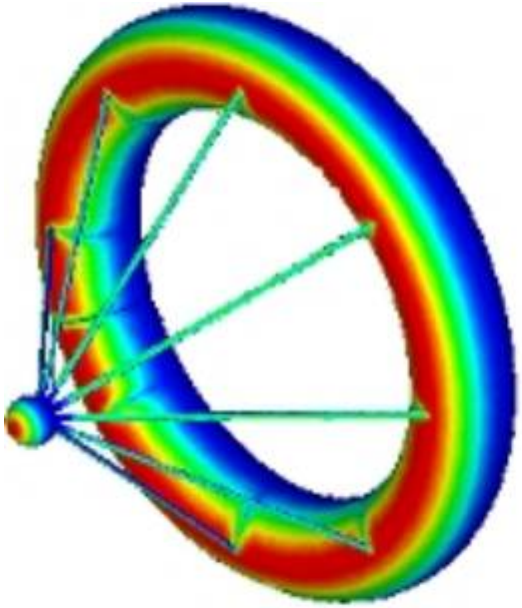
The ELORET/ARC lab and sensor fabrication equipment

Ball Aerospace Trailing Ballute Development

- **Summary** - Ball Aerospace is performing critical initial trades and feasibility assessment for an aerocapture concept that utilizes a towed inflatable toroid.
- **Accomplishments**
  - –Completed configuration trades and guidance algorithm development
  - –Completed preliminary aeroheating analyses
  - –Material testing at elevated temperatures, seaming approaches investigated
- **Plans**
  - –Complete environmental testing for materials
  - –Conduct aerodynamic testing and aeroelastic analysis
  - –Develop an Earth flight demonstration concept



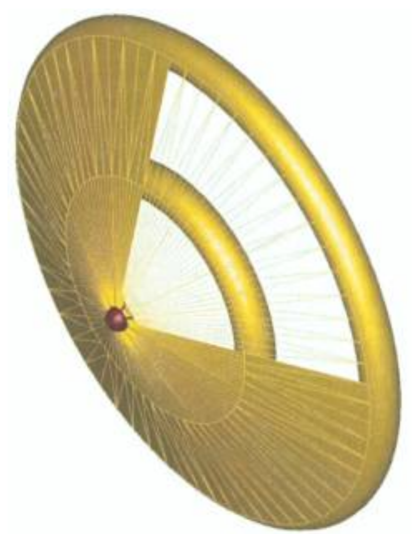
Sample output from recent concept design studies



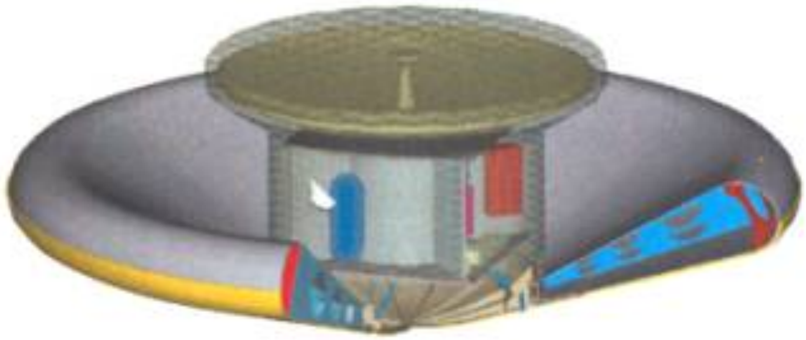
Sample output from recent aerothermodynamic CFD heating analyses

Cycle 2 NRA Selections - Aerocapture

Title	Center Awarded	Contract Awarded	Major Products
Clamped Afterbody Decelerator		Ball	• Design of inflatable afterbody ballute deceleration system • Builds on previous work with Gossamer Program
Inflatable Forebody Aerocapture Concepts		Lockheed Martin	• Design of inflatable aeroshell system • Builds on previous work for Mars Program



Ball Aerospace – Afterbody Decelerator



Lockheed Martin – Inflatable Aeroshell

Summary

- In-Space Propulsion is chartered to develop primary propulsion technologies from TRL3 to TRL6 in 3-5 years
- ISP is making significant investments in technologies synergistic with entry probes and ongoing entry missions
  - TPS
  - Structures
  - Sensors
  - Aerothermal modeling
  - Systems analysis and performance
  - Ballutes
- Aerocapture as a technique likely will not be adopted until a flight demonstration (as early as 2008), but subsystem technologies can be infused in the near future

Backup

Aerocapture Roadmap